A LABORATORY METHOD FOR DETERMINING THE SKIDDING RESISTANCE OF BITUMINOUS PAVING MIXTURES

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A LABORATORY METHOD FOR DETERMINING THE SKIDDING RESISTANCE OF BITUMINOUS PAVING MIXTURES

J. W. Shupe[1] and W. H. Goetz[2]

One of the major problems currently confronting the highway engineer in many areas of the United States is to construct highways which will exhibit satisfactory anti-skid characteristics for a reasonable length of time. All pavement surfaces can develop adequate skidding resistance in a dry state. In fact, some of the surface types which are extremely slippery when wet have shown very high skidding resistance in the dry condition (1, 4). The problem, therefore, is to design highways which retain good anti-skid characteristics even when water is standing on the pavement surface.

The majority of the highways which have been constructed recently, whether of portland cement or of bituminous materials, have possessed adequate wet skidding resistance when new. Unfortunately, on many of these surfaces this initial anti-skid resistance has been short-lived. As a result, it has become increasingly important to give some consideration to the change in skidding resistance of pavement surfaces due to the polishing effects of traffic.

There is little existing knowledge, other than experience on specific surfaces, with which to predict the long term behavior of the many different surface types. Those contributions that have been made

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have resulted, for the most part, from field investigations. By testing a large number of highway surfaces and performing a statistical analysis on the results, it is possible to develop some general relationships for the various surface types (2, 3, 4).

The skidding resistance of a pavement surface as determined by a highway investigation, however, represents a composite value of a seemingly endless list of variables, including factors pertaining to the aggregate, the binder, traffic and age, and the condition of the surface during testing. It is impossible in a field investigation to evaluate the separate effect of each of these inter-related variables. It was felt that the control and consistency inherent in a laboratory investigation would permit a more accurate determination of the basic factors contributing to slipperiness of pavement surfaces. Therefore, the laboratory equipment and testing procedure were developed with this end in mind. Although this paper relates entirely to bituminous mixtures, many phases of the testing procedure pertain equally well to portland cement concrete surfaces, which currently are being investigated in a similar study.

DEVELOPMENT OF LABORATORY TESTING EQUIPMENT

There were two separate phases in the development of a satisfactory laboratory method for evaluating the resistance of different types of bituminous paving mixtures to the polishing effects of traffic. The first was to develop suitable equipment and procedure for measuring the skidding resistance of a test specimen in the laboratory. Next, and equally important, was the selection of a laboratory method, with related instrumentation, for simulating the wear and polishing effect that a pavement surface receives under the action of traffic.

In considering the objectives of the program in light of previous research, the following requirements seemed essential to the satisfactory determination of the skidding characteristics of test specimens by a laboratory procedure:

1. The equipment should be [illegible] specimens molded in the laboratory and to samples [illegible] from the highway surface.
2. [illegible] the [illegible] [illegible] during testing.
3. In order [illegible] relative speed between the [illegible] should be high. On the basis of [illegible] a speed of [illegible] mph appeared [illegible].
4. The type of [illegible] between the [illegible] and the surface [illegible] should be such that the [illegible] of the aggregate [illegible] which occurs during braking of a [illegible] on a highway surface is duplicated.
5. The results should be easy to obtain and relatively free from individual bias. To this end, automatic recording would be preferable to some method of dial or scale reading during testing.
6. In order to accomplish a large scale program of research, the equipment should be rugged and capable of producing a large amount of reproducible data over a prolonged period of testing with a minimum of servicing, adjustment, and repair.

With [illegible] procedure, the primary criterion [illegible] as nearly as possible, [illegible] would exhibit [illegible] action of heavy traffic.

The [illegible]

With the objectives listed in the [illegible] as guide, plans were drawn up, and the [illegible] as illustrated in Figures 1 and 2. [illegible] discussion of the essential [illegible] a brief explanation as to the [illegible] will make reference to Figure 1, the [illegible] Skid-Test Apparatus.

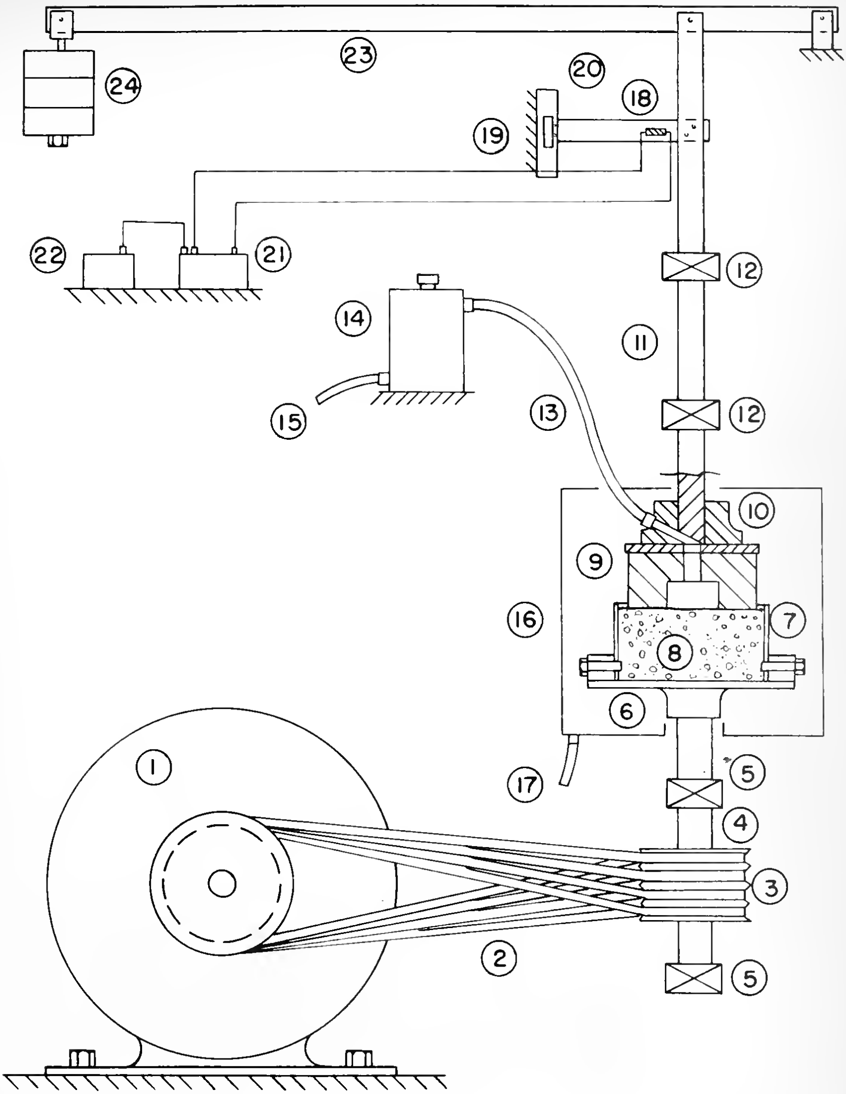


FIG. 1 SCHEMATIC DIAGRAM OF LABORATORY SKID-TEST APPARATUS

KEY TO FIGURE 1

Identification of the Essential Elements of the Laboratory Skid-Test Apparatus

1. 40 hp 3-phase electric motor operating at 1760 rpm.
2. 4 V-belts.
3. Lower-shaft pulley.
4. Lower shaft;rotating at 2500 rpm.
5. Lower-shaft roller bearings.
6. Lower-shaft bracket and mold bearing plate.
7. Test-specimen mold.
8. Test specimen.
9. Rubber testing shoe.
10. Upper-shaft bracket.
11. Upper shaft; nonrotating.
12. Upper-shaft sleeve bearings.
13. Flexible water line.
14. Turbulence chamber.
15. Water inlet; line pressure.
16. Water and particle shield.
17. Water drain.
18. Torque take-off beam with two Baldwin SR-4 strain gages.
19. Roller bearing.
20. Vertical race for torque beam roller bearing.
21. Brush Model BL-320 Universal Analyzer.
22. Brush Model BL-202 Direct Inking Oscillograph.
23. Loading bar.
24. Loading weights.

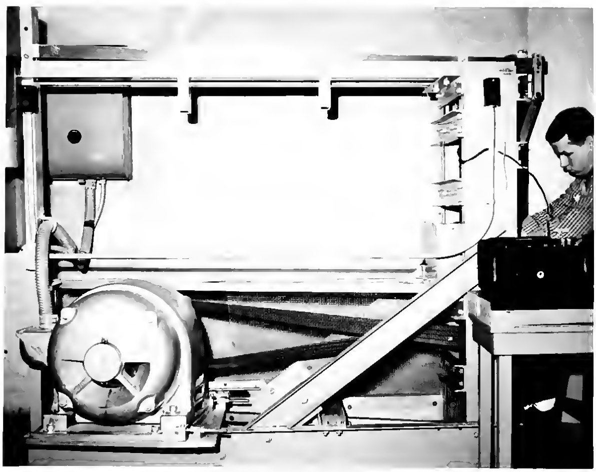


Fig. 2 Laboratory Skid-Test Apparatus

The power required to maintain a constant rotational speed of the test specimen during testing is supplied by a 40 hp electric motor (1)*. Anticipated torque requirements were only about one-half of this value, but since this heavier unit was available it was incorporated into the design. This did necessitate a sturdier frame than otherwise would have been required, but resulted in an overall saving when compared to the cost of a smaller motor. It also provided a margin of safety should subsequent research require a greater torque output.

The power is transmitted to the lower shaft through four V-belts (2). The pulley on the lower shaft (3) is somewhat smaller than that on the motor, so the rotational speed of the lower shaft assembly, including the test specimen, is approximately 2500 rpm as compared to 1760 rpm for the motor. This rotation results in a relative velocity between the test specimen and testing shoe of slightly over 50 mph at the mean radius of the area of contact.

The lower shaft (4) is mounted in two roller thrust-bearings (5), which are rigidly anchored to the frame of the machine. The bracket (6) is fastened to the lower shaft and serves as the base plate for the mold (7) and the test specimen (8).

The testing shoe (9), which is detailed in Figure 3 and illustrated in Figure 4, is made from rubber discs supplied by the Firestone Tire and Rubber Company. The ASTM designation for this rubber is R630B, and it is representative of passenger car tire tread compounds, having a Shore "A" durometer reading of 65. The testing shoe is anchored to the back-up plate by four 1/2-inch diameter pegs and a rubber-to metal adhesive with the trade name of "Loxite-6000", also furnished by the Firestone Company.

* Circled numbers refer to the corresponding part number in Figure 1.

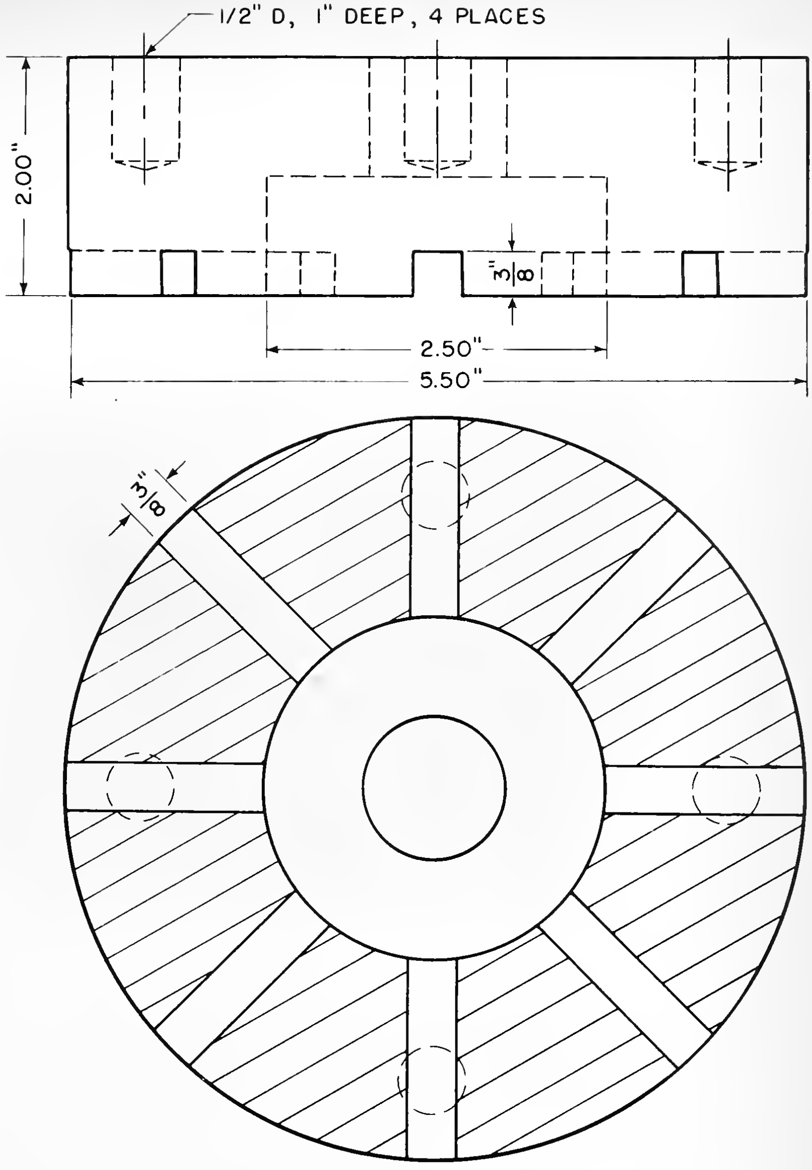


FIG. 3 TESTING SHOE FOR SKID-TEST APPARATUS

Fig. 4 Rubber Testing Shoe

Referring to Figure 3, the area in contact with the test specimen consists of eight segments, each having an area slightly over 1-3/4 square inches, giving a total contact area between testing shoe and test specimen of 14.4 square inches. The total vertical force between the two sliding surfaces during testing is maintained at 400 pounds, resulting in a unit pressure of about 28 psi. The slots were provided in the testing shoe to permit the free passage of water over the test specimen, to prevent overheating of the specimen or testing shoe, and to simulate, to a limited degree, the tread that is present on the majority of vehicular tires.

After prolonged testing the edge of the slot becomes rounded and, occasionally with a particularly abrasive aggregate, the surface of the testing shoe may become scoured. When either of these conditions exists the testing shoe is removed from the skid-test apparatus and the face redressed. This is done very simply by mounting the shoe and backup plate in a magnetic chuck and grinding off approximately 1/32 of an inch of rubber. Before being used again for test measurements the shoe is honed by simulating a test run on a Kentucky rock asphalt specimen.

The testing shoe is attached through a back-up plate to the upper bracket (10) which, in turn, is keyed to the top shaft (11). The top shaft is supported in two sleeve bearings (12), which maintain radial alignment of the shoe for all vertical positions. The top shaft assembly does not rotate during testing, and the torque developed in this shaft, due to the sliding friction between the test specimen and testing shoe, is proportional to the skidding resistance of the surface type as represented by the test specimen.

This torque is reacted by a cantilever beam (18), on which are mounted two Baldwin SR-4 strain gages. Original design had these gages located directly on the vertical shaft, but it was felt that the secondary effects of bending and direct stresses in the shaft would result in inaccuracies in the determination of the torque. The two gages are located at the vertical neutral axis on opposite sides of the beam and are connected into opposing legs of the Wheatstone Bridge circuit, so that any direct force or vertical bending that might be present is not reflected in the torque determination.

In order to ensure that the cantilever torque take-off beam reacts the torque through a fixed lever arm for all vertical positions, a roller-bearing (19) is attached to the end of the beam. This bearing makes essentially point contact with the bearing race (20), which is a one-inch diameter steel rod rigidly attached to the frame and parallel to the top shaft.

The strain gages are attached as close to the top shaft as is practical in order to take advantage of the largest possible bending moment. The torque developed in the shaft results in a bending moment in the beam, causing a change in resistance in the SR-4 strain gages, which is transmitted to the strain analyzer (21) and results in a deflection of the pen in the automatic recorder (22).

Figure 5 illustrates some typical oscillograms for three different surface types. These three test specimens were all cored from highway pavement surfaces, but oscillograms for laboratory specimens are similar in form.

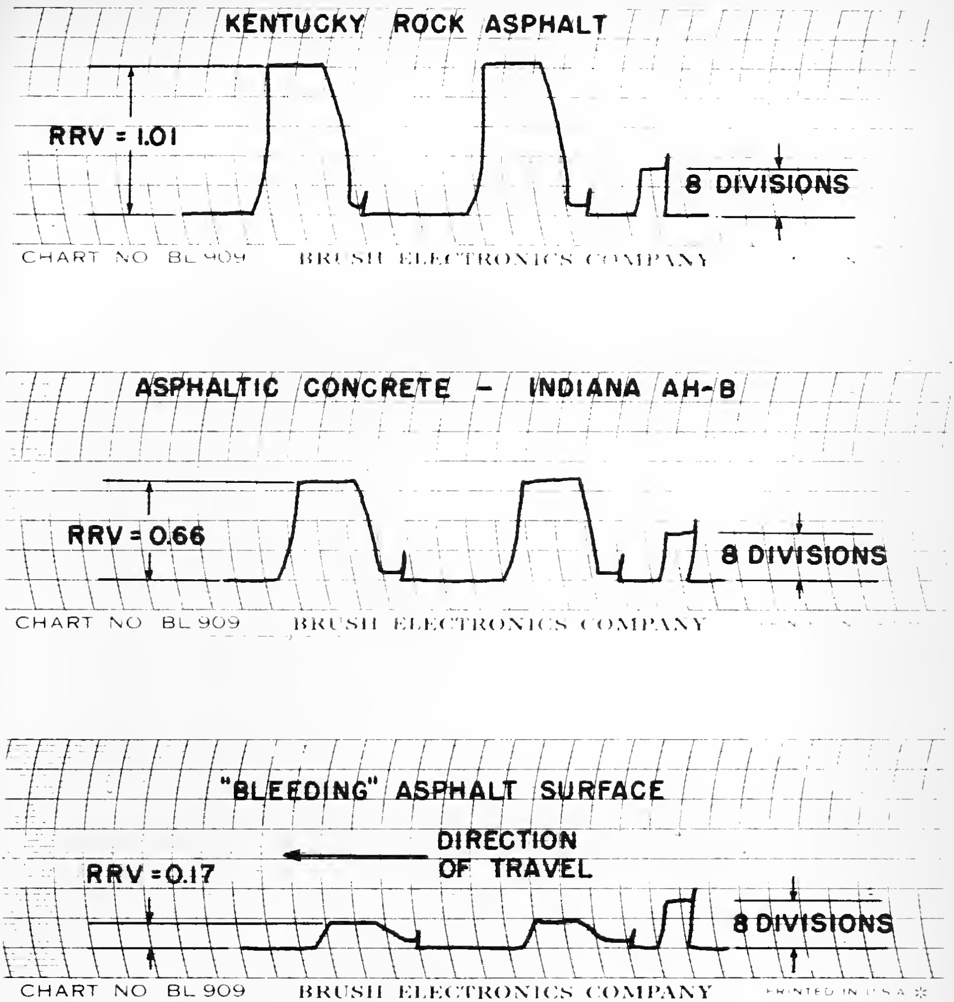


FIG. 5 OSCILLOGRAMS FROM THE LABORATORY SKID-TEST APPARATUS

The skidding resistance of each of the surfaces is represented by a numerical value called the relative resistance value or RRV. This skid-test apparatus, like most of the methods for determining the skidding resistance of test surfaces, evaluates the different surface types on a relative basis. No effort was made to convert this reading to a coefficient of friction. It was decided that since Kentucky rock asphalt surfaces consistently exhibit the best skidding resistance when wet, as has been determined by previous research (1, 5), attentuation in the analyzer would be adjusted so that the deflection of the pen, due to the torque developed by a Kentucky rock asphalt specimen, would be approximately five major, or 25 of the smaller, divisions. By arbitrarily assigning a value of unity to the resistance developed by the Kentucky rock asphalt, the relative resistance values of the other surface types, with respect to a RRV for Kentucky rock asphalt of approximately 1.00, could be determined to the nearest 0.01.

The three surface types in Figure 4 show relative resistance values of 1.01, 0.66, and 0.17, respectively. This represents the maximum range encountered in the testing program, since Kentucky rock asphalt exhibited the best anti-skid characteristics, and a "bleeding" asphalt surface, the poorest of all the surface types tested.

Before each of the testing records in Figure 5 is noted a blip labeled, "8 divisions." This is the pen deflection caused by the calibration resistance in the analyzer. It was found that by adjusting the a-c gain so that the calibration resistance caused a pen deflection of eight of the small divisions, the deflection resulting from a Kentucky rock asphalt test specimen would be approximately five of the major divisions. Therefore, this 8-division deflection due to the cali-

bration resistance was established as the standard sensitivity, and was adjusted, if necessary, before each test.

Two 3-second skids were made on each test specimen. The relative resistance value was based on the second trace, as illustrated in Figure 4. Frequently the RRV for the first skid fell off rather sharply so that there was as much as 0.06 to 0.08 difference in RRV between the beginning and end of the skid. By the second skid, however, the trace was usually sufficiently stable so that an accurate determination of the RRV was possible. It was felt on the basis of repeated tests that an accuracy of plus or minus 0.01 could be achieved if care was taken to assure that the 8-division sensitivity was maintained.

A constant load of 400 pounds is applied during testing by attaching a load (24) of 58.7 pounds to the end of the loading bar (23). This bar is pivoted at the far end so that a mechanical advantage of slightly over six is achieved. This, in addition to the weight of the bar itself and of the upper-shaft assembly, gives a constant normal force between the two sliding surfaces during testing of 400 pounds, or an equivalent unit pressure of about 28 psi.

The remaining elements of the skid-test apparatus pertain to the water system, which keeps the test surface in a lubricated condition during testing. The water is admitted to the test specimen through a hole located in the center of the testing shoe (9), after passing through a passage drilled in the upper-shaft bracket (10) and the upper shaft (11), as illustrated in Figure 1.

A flexible water line (13) is used so that the system can operate for different vertical positions of the upper-shaft assembly. The turbulence chamber (14) has no function in the testing operation, but has

[illegible] in the polishing procedure can be discussed [illegible]

A constant line pressure is maintained at the water inlet (15) resulting in a [illegible] flow of water on the test specimen of 1.5 gallons per minute. All of this water is admitted to the specimen through the center of the testing shoe and flows over the specimen through the slots provided in the shoe.

The water spun from the specimen at 2500 rpm, so a shield (16) [illegible] the water and channel it to a drain (17). This shield is intended to be not only waterproof, but also "bulletproof"; it was constructed from 1/4-inch steel plate. Should a bolt come loose at 2500 rpm or a large piece of aggregate be dislodged from the surface, the shield would be adequate to prevent the flying particle from causing damage to equipment or personnel.

Briefly summarizing the test procedure: first, the motor is turned on, causing the specimen to rotate at 2500 rpm. Next, the water valve is opened and the recording equipment started to establish the zero reading on the oscillogram. Then, the weight is lowered manually to allow the full [illegible] pound force to bear on the test specimen for two [illegible]-second intervals. During this period the frictional torque developed on the test shaft is automatically recorded, indicating the skidding resistance of the test specimen. The weight is then secured and the water, recording equipment, and electric motor turned off. The total time lapse is approximately 15 seconds.

Equipment and Procedure for Simulating Traffic Wear

The procedure and associated instrumentation for simulating the wear and polishing effect that a pavement surface experiences under the action of traffic evolved as a result of investigating different methods of polishing on over a hundred test specimens. Various polishing compounds were used, including carborundum, alundum, emery, quartz, and limestone, varying in particle size from 0.005 to 0.30 millimeter. Contact pressures ranging from 1 to 26 psi were tried at speeds of 33 and 2500 rpm. Polishing was attempted both with a rolling rubber cone and with a sliding rubber disc. The length of time for a given polishing cycle was varied from 30 seconds to 30 minutes, with the number of cycles per given specimen varying from two to twelve.

It was relatively easy to grind the test specimens down, with the skid-test apparatus being used for this purpose. Referring again to Figure 1, a charge of abrasive material was first placed in the turbulence chamber (14). Then as the valve was opened and water rushed into the chamber from the inlet (15), the abrasive was agitated into suspension and flowed down the outlet line (13) to the specimen. The inlet pipe was brazed to the circular brass chamber at an angle of 45 degrees to the tangent to encourage a swirling action, which would permit adequate transport of the abrasive. Calibration tests showed that with full line pressure at the water inlet, less than 5 grams of an initial charge of 500 grams of No. 40 to No. 80-mesh sand remained in the turbulence chamber after 60 seconds. For limestone mineral filler, less than 1 gram was present in the chamber after 60 seconds.

The [illegible]
lar in [illegible]
diameter [illegible] larger [illegible]
than the [illegible]
sure that [illegible]
Also, the [illegible]
slightly [illegible]
designation of R/[illegible]

By starting with a [illegible]
to keep them [illegible]
ground down [illegible]
size of [illegible] spe-
cimen [illegible] on of
the resulting [illegible] highway
showed that there [illegible] of
the two. The [illegible] highway [illegible] was
not a [illegible] datum, [illegible]
polished particles of [illegible] the
surrounding matrix of [illegible] could
not be duplicated [illegible]

The [illegible] intended to
supply the rolling [illegible] that a [illegible] experiences due to traffic,
in order to achieve the particle [illegible] and arrangement that exists
on the highway surface. Figure 7 [illegible] being rolled at 33 rpm
in a Minitrack apparatus. This equipment originally was developed
some years ago for rolling test specimens on a circular track with
a small rubber tire. Only slight modification was necessary to adapt
the existing equipment to accommodate the 6-inch diameter specimen.

Fig. 6 Conical Rubber Rollers for Obtaining Adequate Particle Orientation at the Surface of the Test Specimen

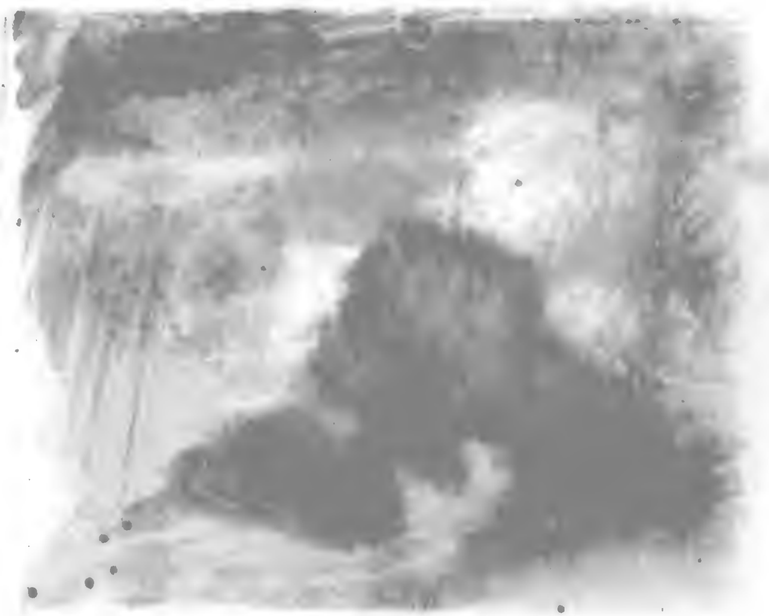


Fig. 7 Rolling Test Specimen with Conical Rollers in the Minitrack Apparatus

Rolling in this manner resulted in an overall densification of the test specimen with the coarse aggregate particles becoming somewhat more prominent at the surface than was noted at the completion of the molding procedure.

Rolling was initially attempted with this equipment without the use of the center post. At 140 F some of the mixes shoved excessively and bunched up at the center of the specimen. The post was then incorporated into the design, but located flush with the bottom of the rollers. This eliminated the shoving, but since the post took most of the vertical load, only a slight amount of particle reorientation was accomplished. The final position, as shown in Figure 6 with the rollers extended 1/8 of an inch below the post, represented a compromise in which sufficient confinement was provided without sacrificing an adequate amount of particle orientation.

Another operation which seemed to enhance the effect of the coarse aggregate at the surface was to polish the specimen at 33 rpm in the Minitrack, using the conventional polishing shoe previously described, with limestone mineral filler suspended in water as an abrasive. This operation polished the coarse aggregate particles slightly, and also appeared to erode away some of the surrounding matrix of fine aggregate and asphalt, so that the resulting surface texture more nearly approximated that of a sample removed from the highway surface. It was necessary to give the specimen a final polish in the skid-test apparatus in order to smooth off the rough edges exposed by this operation.

This left the test surface in a clean, polished condition. By rolling the specimen again at 140 F for a short time with the conical rollers, a very light asphalt film could be made to coat the aggregate.

This coating discolored the aggregate somewhat, but did not result in a solid black asphalt appearance, so seemed more representative of an oily rather than an asphaltic film. It was felt that although this treatment did not exactly duplicate the oil drippings, worn rubber, and debris film that exist on highways during certain seasons of the year (2), the relative resistance values for this final condition would be indicative of the susceptability of the surface types, as represented by the test specimens, to this seasonal effect.

The rather complicated wear and polishing procedure as finally evolved consists of the following steps:

1. The specimen is rolled for two minutes at 140 F in the Minitrack at 33 rpm with a total load on the two rollers of 100 pounds.
2. Coarse wear is accomplished in the skid-test apparatus with a contact pressure between the shoe and test specimen of 5 psi. Each specimen is subjected to three wear series as follows:
    a) 300 grams of No. 3/0 quartz* for 60 seconds.
    b) 500 grams of No. 5/0 quartz* for 60 seconds.
    c) 400 grams of limestone mineral filler* for 60 seconds.

*Gradation is listed in Table 1.

3. Particle orientation and texture is accomplished in the Minitrack at 33 rpm.

   a) Two minutes rolling at 140 F with a total load of 100 pounds on the two rollers.

   b) Ten minutes of wear, using 10 psi contact pressure with the polishing shoe and 25 grams of limestone mineral filler.

4. Final polish is given the specimen in the skid-test apparatus at 2500 rpm.

   a) 250 grams limestone mineral filler, 15 psi contact pressure, for 30 seconds.

   b) 250 grams limestone mineral filler, 28 psi contact pressure, for 30 seconds.

   c) No abrasive, 28 psi contact pressure, for 30 seconds.

5. The final operation is to coat the aggregate particles in the specimen surface with a light asphalt film, simulating seasonal road film, by rolling in the Minitrack at 140 F for 1 minute with a load of 100 pounds on the conical roller.

As previously stated, this procedure was intended to result in a specimen which, both in appearance and in skidding resistance, closely duplicated a similar mix after an appreciable amount of traffic wear. It was not the intention to arrive at the ultimate slippery condition for all surface types. However, the above procedure does cause a specimen made with an aggregate having poor polish resistant characteristics to approach its most slippery condition. It was felt that by holding the polishing effort constant, a relative measure of the resistance to polishing of the different aggregate types could be obtained which would

be more realistic than subjecting each of the test specimens to sufficient polishing to cause it to arrive at its most slippery condition.

It was found that extreme polishing could cause test specimens made from the more resistant aggregates, such as high-quartz gravel, to have relative resistance values below 0.4, which is equivalent to a passenger car stopping distance from 30 mph of approximately 150 feet. Since field tests on surfaces of this nature (3) indicate that this material is resistant to polishing, these data did not seem realistic.

During a complete polishing cycle each portion of the test area receives over 80,000 individual passes either from the conical rollers or the separate segments of the testing shoe. Figures 8 and 9 indicate the appearance of two typical specimens after being subjected to this polishing series. Figure 8 illustrates a limestone which exhibited poor polishing characteristics, and Figure 9 a highly resistant quartzite. These photographs were made following the final polish, but prior to the final rolling which serves only to coat the aggregate slightly.

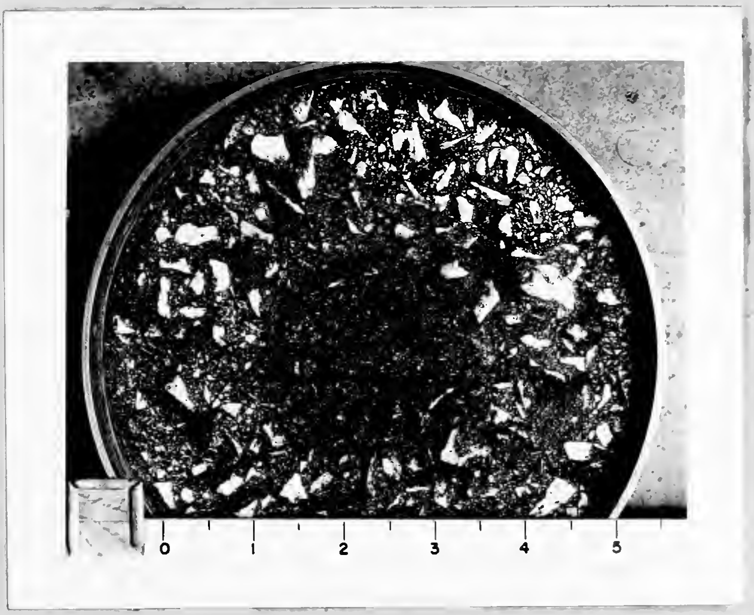


Fig. 8 Surface Texture at the Completion of the Wearing Procedure for a Limestone Aggregate

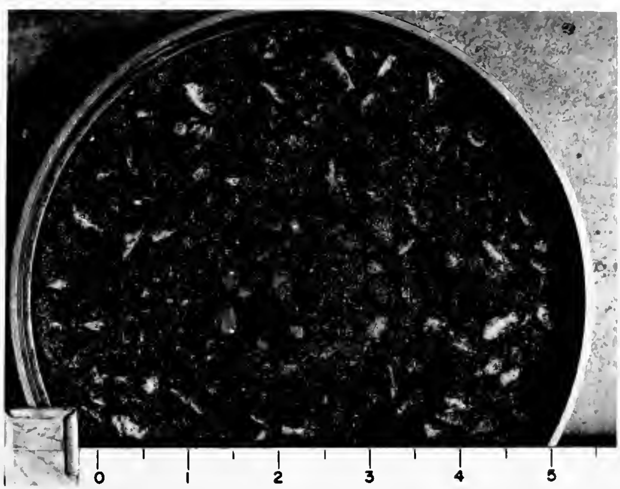


Fig. 9 Surface Texture at the Completion of the Wearing Procedure for a Quartzite Aggregate

FIELD CORRELATION STUDY

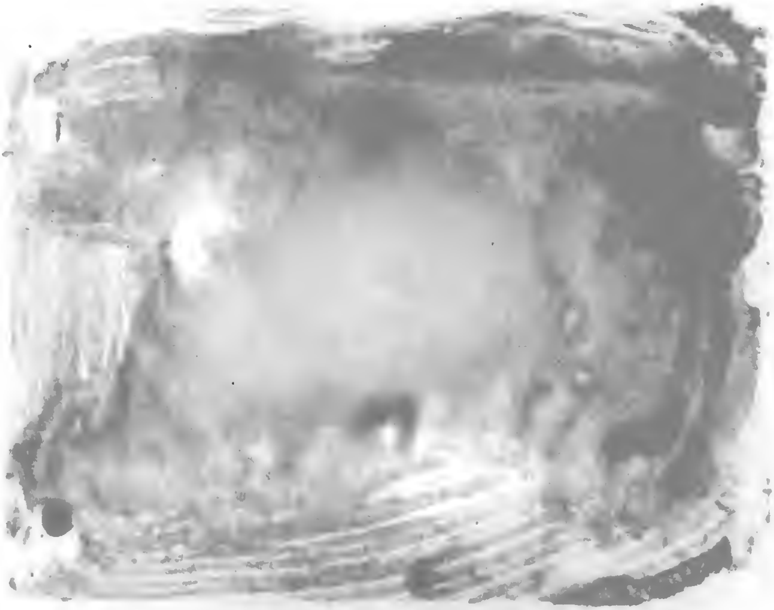
In order to determine if the laboratory skid-test apparatus would evaluate the various test specimens in a realistic manner, a field correlation study was performed. Passenger car stopping-distance tests were made on selected highway surfaces with the testing equipment of the State Highway Department of Indiana. Cores were obtained from these test sections and the relative resistance values determined in the laboratory. A comparison of the results of these two methods was then made.

Field Test Equipment and Procedure

The passenger car stopping-distance test equipment was developed by the Joint Highway Research Project of Purdue University and is described in detail by Grunau and Michael (5). The equipment was transferred to the State Highway Department of Indiana in 1956, and was made available by this agency for the correlation study.

Briefly, the essential components of this equipment consist of a 1955 Ford 2-door sedan equipped with an electrically-operated, vacuum braking unit for instantly locking all four wheels, and a Wagner Stopmeter, which is a fifth wheel for indicating both the speed at which the brakes are applied and the total distance required to skid to a stop after the brakes are actuated. Figure 10 shows the Wagner Stopmeter attached to the test vehicle, and also the vacuum braking system located in the vehicle luggage compartment.

Fig. [illegible] The Wagner Stopmeter A[illegible] to the Rear of the Test Vehicle



For this correlation study all skidding tests were performed with the surfaces in a wet condition. A tank truck equipped with spraying apparatus was used for wetting down the surfaces before each test. Traffic control was required both for the watering operation and during the actual testing. A crew of five men was supplied by the State for the wetting and traffic control, while the skidding tests themselves were performed by two members of the Purdue staff.

The following procedure took place at each of the test sections. The surface was first thoroughly drenched with a slow pass of the watering truck. The test vehicle was then brought up to an indicated speed on the Wagner Stopmeter of 30 mph and the brake-actuator button depressed, causing all four wheels to lock. The distance required for the vehicle to skid to a complete stop, as measured by the Wagner Stopmeter, was then recorded. This completed one test. Two more tests of the same section were performed in a like manner with the surface receiving a relatively light water treatment prior to each test.

As previously mentioned, the brakes were applied at an indicated speed on the Wagner Stopmeter of 30 mph. On computing coefficients of friction for some of the test surfaces and comparing these values with results of studies in other states, some doubt arose as to the accuracy of the speedometer. A rough check with a radar speed-determination unit showed that with an indicated speed of 30 mph on the Wagner Stopmeter, the vehicle was actually traveling between 33 and 34 mph. This had no adverse effect on the correlation study, which was merely a comparison of two methods of evaluating the skidding resistance of different test surfaces. However, no comparisons should be made between these results and 30 mph stopping distance measurements of other research studies.

Preparation of Test Specimens from Pavement Cores

Three cores were removed from the pavement at each test section. These cores were taken from the outside wheel track, and were evenly distributed longitudinally along the length of the skidding area of the stopping-distance tests.

The cores were drilled with a Model 12 Abrasive Speed Drill, manufactured by Howe-Simpson, Inc. of Columbus, Ohio. The resulting specimen was a core approximately 5-3/4 inches in diameter and, depending upon surface type, anywhere from 3/4 of an inch to over 3 inches thick. In addition, the bottom of some of the specimens were extremely irregular. These specimens were mounted in the molds in a paste consisting of three parts of type I portland cement to one part plaster of Paris, with sufficient water to provide adequate workability. Figure 11 shows sawed-sections of some typical pavement cores. The top specimen is an asphaltic concrete made with limestone; the middle specimen is from a new asphaltic concrete pavement containing gravel, in which some difficulty was encountered in obtaining a core; and the bottom specimen shows a 1/2-inch layer of Kentucky rock asphalt on a bituminous-coated gravel base.

After the cementing paste hardened sufficiently, the specimens were tested in the skid-test apparatus in the same manner as for the conventional laboratory test specimens.

Fig. 11 Cross Sections of Pavement Cores Mounted in a Mortar for Testing

Description of Highway Test Sections

Only a brief description of the various test sections is included since it was not the purpose of this correlation study to evaluate the different surface types, as such, and no systematic sampling was made with regard to selecting sections having comparable traffic and age. As a result, no conclusions should be drawn on the basis of these limited data as to the relative skid resistance of the various surface types.

In planning the correlation study, 32 test sections were chosen in west-central Indiana that were representative of a wide range of bituminous surface types. Three stopping-distance skid tests were made at each location. Examination of the test data led to the selection of 20 of these sections as correlation sites from which three test specimens were to be cored. At two of these sites it was impossible to obtain adequate cores, so the following correlation study was based upon 18 test sections.

Figures 12 through 17 illustrate the six general surface types into which these 18 test sections were classified.

Fig. 12 Asphaltic Concrete - Limestone

Fig. 13 Surface Treatment - Limestone

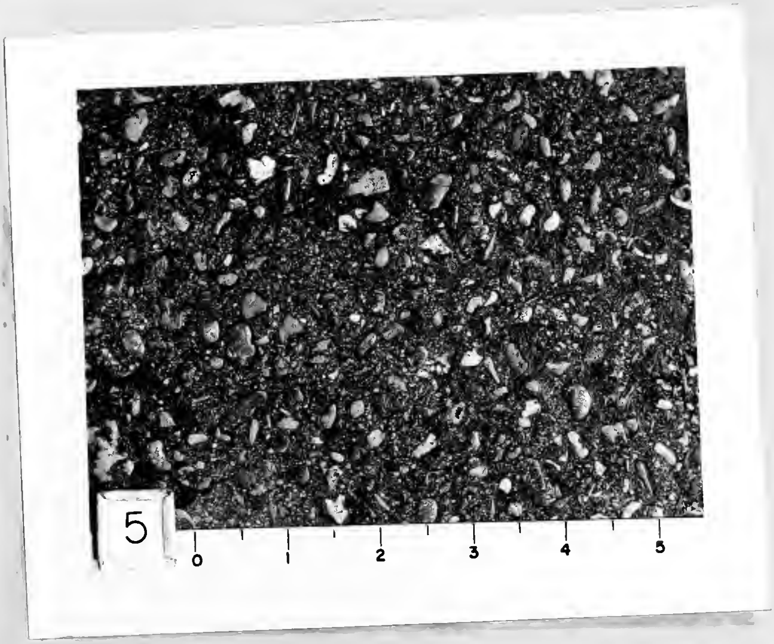


Fig. 14 Asphaltic Concrete - Gravel

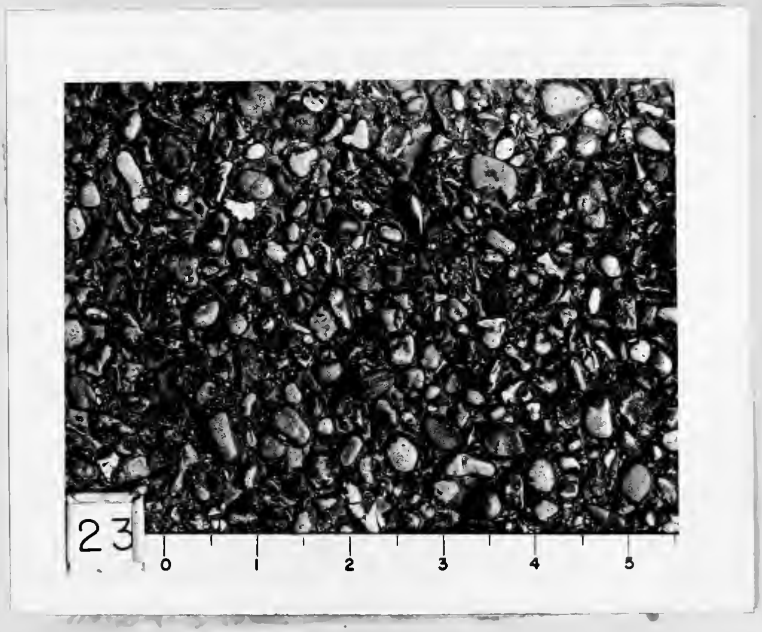
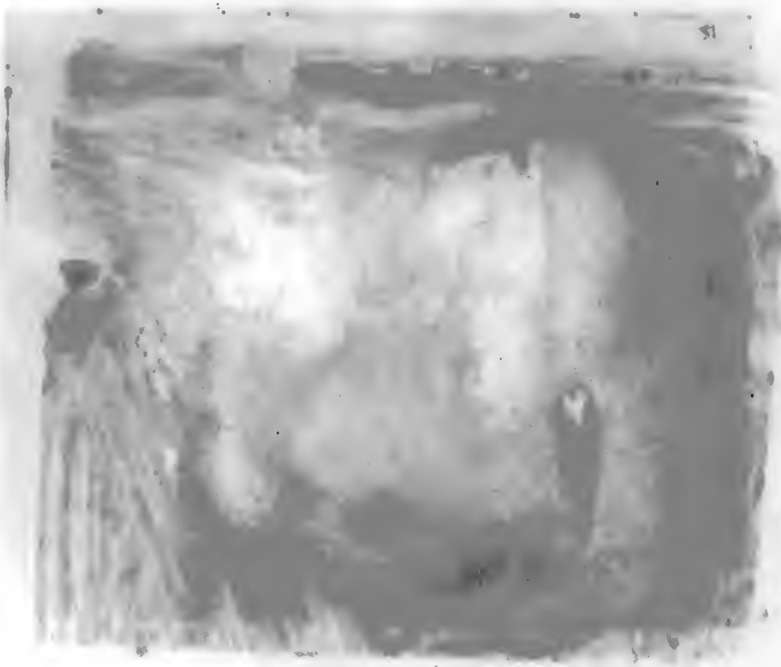


Fig. 15 Surface Treatment - Gravel



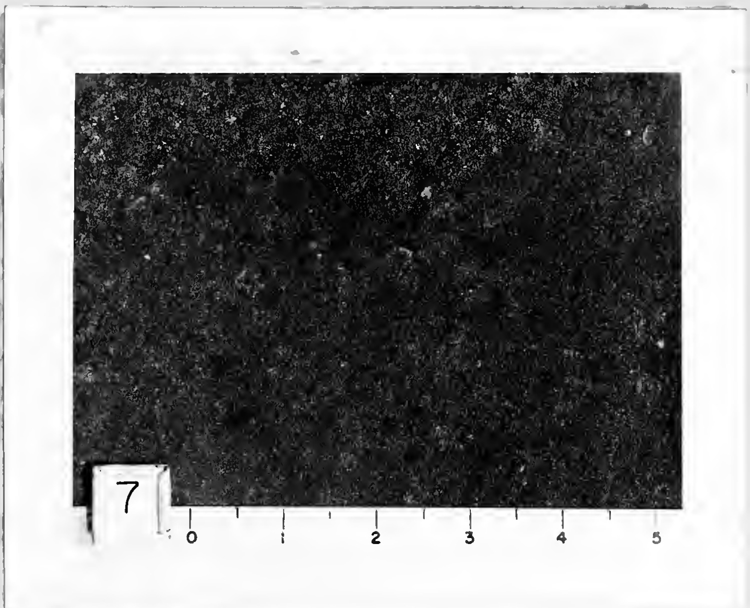


Fig. 15 Kentucky Rock Asphalt Surface

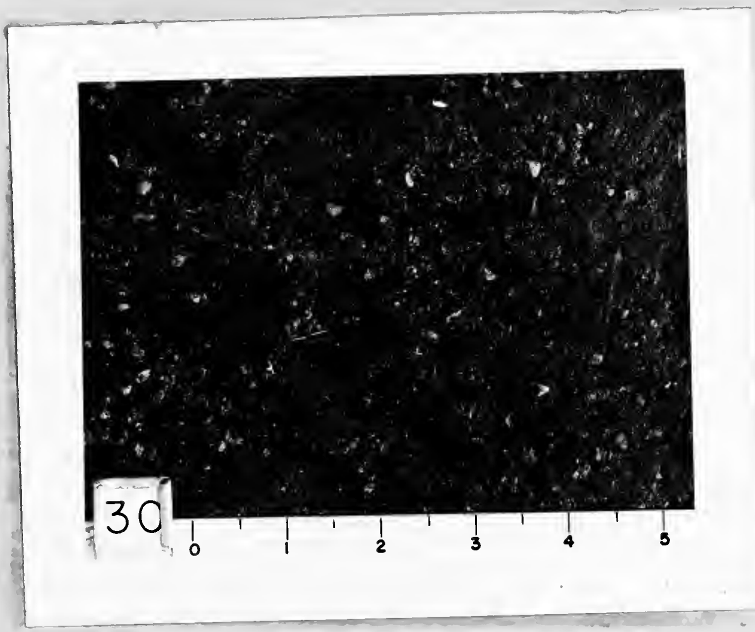


Fig. 17 "Bleeding" Asphalt Surface

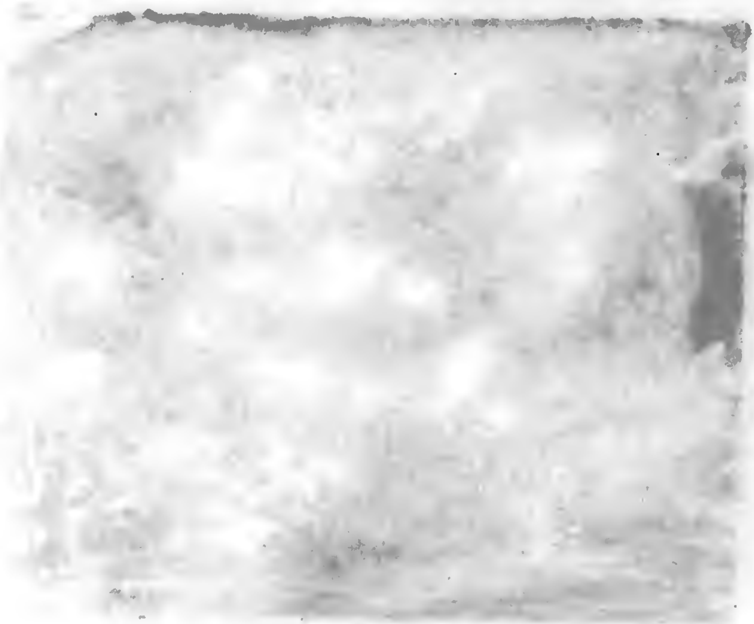


Figure 12 is representative of those asphaltic concrete surfaces in which the coarse aggregate consisted of limestone. Referring to Table 2, test sections 9, 12, and 13 are included in this classification.

Figure 13 is typical of test sections 4, 11, 14, and 26, which are identified rather broadly as limestone surface treatments. All of these surfaces either were given a final surface treatment involving separate applications of asphalt and aggregate, or were of similar texture, so that the resulting area of contact on which the tire skidded consisted almost entirely of coarse aggregate.

Figures 14 and 15 represent, respectively, the same surface types as Figures 12 and 13, except that gravel rather than limestone was used in these bituminous mixtures. Test sections 3, 5, and 6 are asphaltic concretes made with gravel, and sections 1, 16, 23, and 27 are gravel surface treatments.

Three Kentucky rock asphalt surfaces were included in this study. This material occurs in Kentucky in a formation in which a Mississipian sandstone is impregnated with asphalt. This type of surface is very uniform and fine-textured, as illustrated in Figure 16. Test sections 7, 8, and 24 are Kentucky rock asphalt surfaces.

Test section 30 is a "bleeding" asphalt surface located on a secondary county road. Figure 17 is a photograph of this surface.

Discussion of Field Correlation Results

The results for the 16 surfaces on which both stopping-distance measurements and laboratory resistance values were obtained are listed in Table 2. The stopping distances for the other 14 surfaces are not included, since they contributed nothing to the correlation study. Information listed in this table includes the test section number, to aid in associating Figures 12 through 17 with their appropriate section, and a general surface type classification.

TABLE 2

Summary of Field and Laboratory Skid-Test Results

Number of Test Section	Surface Type	Stopping Distance in Feet			Relative Resistance Value		
		Average	Maximum	Minimum	Average	Maximum	Minimum
1	G-ST	89.5	90.5	88.5	.59	.60	.58
3	G-AC	99.8	102.0	97.6	.66	.67	.65
4	L-ST	92.5	93.0	92.0	.57	.60	.55
5	G-AC	118.5	120.0	116.5	.63	.65	.62
6	G-AC	83.0	83.5	82.5	.75	.75	.74
7	KRA	69.3	70.0	68.0	.99	1.01	.97
8	KRA	62.2	63.2	63.0	1.06	1.09	1.04
9	L-AC	138.0	140.5	135.0	.45	.45	.44
11	L-ST	153.0	153.5	152.5	.35	.36	.33
12	L-AC	85.3	86.1	84.6	.63	.64	.62
13	L-AC	125.3	126.0	124.0	.53	.55	.50
14	L-ST	172.0	176.0	168.0	.34	.35	.34
16	G-ST	103.5	104.0	102.5	.58	.60	.57
23	G-ST	102.0	102.0	102.0	.55	.56	.54
24	KRA	62.0	62.0	62.0	1.01	1.02	.99
26	L-ST	97.7	98.5	96.5	.60	.62	.58
27	G-ST	93.7	96.5	91.0	.57	.60	.54
30	"Bleeding" Asphalt	Greater than 150			.23	.28	.17

Surface Type Identification:

L-AC Limestone - Asphaltic Concrete
L-ST Limestone - Surface Treatment
G-AC Gravel - Asphaltic Concrete
G-ST Gravel - Surface Treatment
KRA Kentucky Rock Asphalt

For each of these sections, stopping distance measurements and relative resistance values are given. The average figures listed in both cases are the arithmetic means of three skids, with the maximum and minimum values also listed to indicate the variability encountered on each of the test surfaces. The stopping-distance measurements are given in feet while the laboratory relative resistance values are dimensionless, but based on a relative resistance value of unity for a Kentucky rock asphalt specimen.

It was impossible to obtain an accurate stopping-distance measurement on test section 30. On each of five attempts the rear end of the test vehicle gradually slid toward the ditch, so that after skidding approximately 150 feet the right rear wheel struck the shoulder and dug in, causing the vehicle to tip appreciably. As a result, about all that can be indicated for the stopping distance on this surface is that it is somewhat "greater than 150 feet," as listed in Table 2.

Figure 18 shows the comparison between the field and laboratory methods of determining the skidding resistance of bituminous surfaces. Results are plotted for only 15 of the test sections so that an equal number of each of the five general surface types illustrated by Figures 12 through 16 would be represented. It was impossible to plot the results for the "bleeding" asphalt section, since no adequate stopping distance measurements were available.

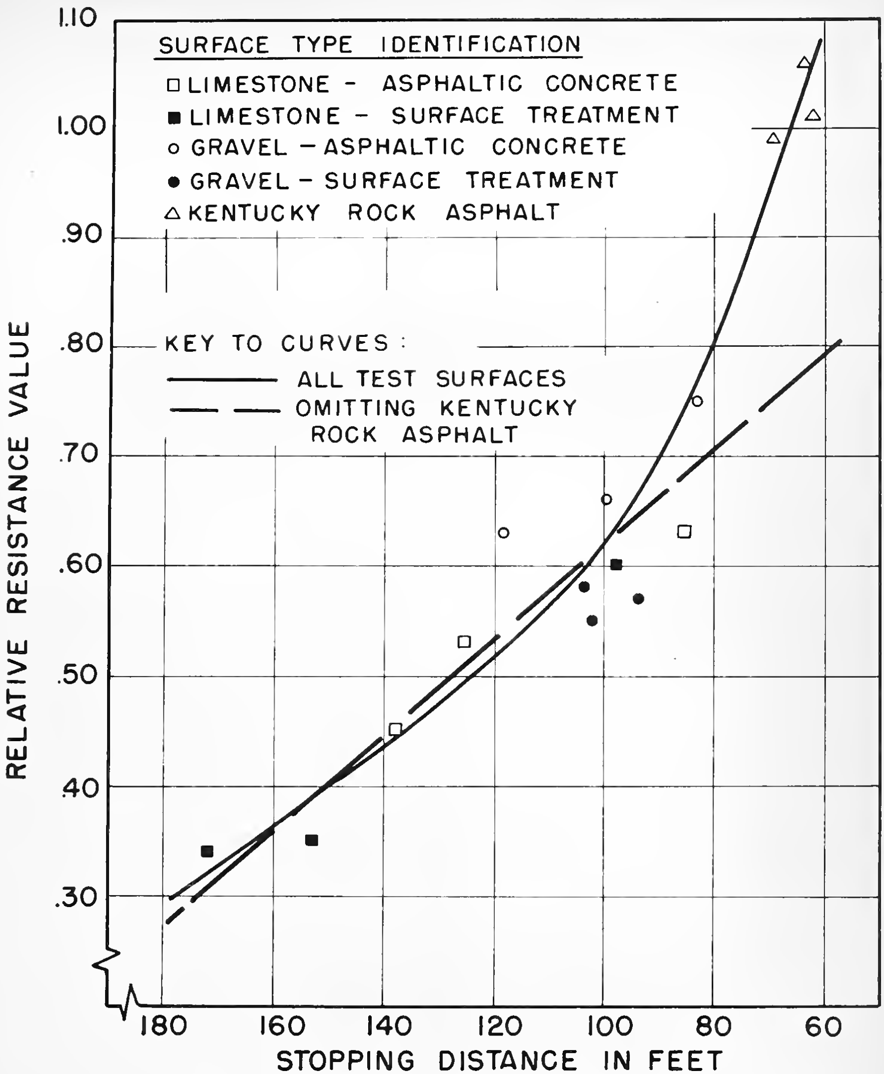


FIG. 18 COMPARISON BETWEEN FIELD AND LABORATORY SKID-TEST MEASUREMENTS

In order to select a curve that represented the best relationship between the 15 plotted points, a second degree regression curve was computed. However, this curve deviated appreciably from the plotted points at the maximum and minimum values, and it was felt that a visual interpretation would give a better indication of the relationship between the two methods. Therefore, the solid curve of Figure 18 was drawn in by eye.

It was anticipated in the planning phase of the correlation study that a linear correlation might exist between the field and laboratory methods of determining skidding resistance. Examination of the plotted points indicated that with the exception of the Kentucky rock asphalt specimens, all of the points did conform fairly closely to a linear plot. Since there was some justification for omitting the Kentucky rock asphalt surfaces in this analysis, as will be discussed later, a correlation analysis was performed on the 12 remaining test surfaces and resulted in a linear correlation coefficient of 0.86, as computed by the method of least squares. The broken line in Figure 18 represents the linear correlation curve for these 12 surfaces.

An examination of the location of the plotted points with respect to the linear correlation line showed that certain surface types consistently fell either entirely above or entirely below the correlation line. This lack of randomness in the location of the plotted points indicated that there was some discrepancy between the field and laboratory methods of evaluation.

Consideration of the test results, in conjunction with a close examination of the test specimens, showed where this discrepancy lay. For surfaces of medium texture there was good agreement in the relative skidding resistance as determined by the two methods. For very open-

textured surfaces, however, the laboratory method indicated relatively poorer anti-skid characteristics than did the stopping-distance method. Conversely, for an extremely dense surface the laboratory method showed relatively higher resistance values than were obtained by field measurements.

This relationship is illustrated in Figure 18 by the location of points corresponding to three different surface types. The very dense Kentucky rock asphalt specimens are all grouped appreciably above the linear correlation line. Similarly the gravel asphaltic concrete surfaces which were quite dense, as shown in Figure 14, also plotted above the correlation line. However, the open-textured gravel surface treatments, as typified by Figure 15, resulted in values which fell below the correlation line. The limestone specimens, for the most part, exhibited a medium texture and did not consistently deviate from the linear correlation curve.

Two of the possible reasons why a difference in surface texture caused a discrepancy between the field and laboratory methods for evaluating the relative skidding resistance of bituminous surfaces pertain to the amount of water present on the surface during testing and to the occurrence of a film of oil and dust on the highway test surfaces. The degree of saturation of the test surface was probably the more significant of the two causes. In the laboratory method the rate of water application was constant for all specimens, and occurred simultaneously with the test itself, so that the surface was thoroughly drenched during actual testing.

In the stopping-distance method, however, there was an appreciable time lapse between the application of the water and the performance of

the skidding test. On very dense surfaces the rate at which water drained from the surface was slow, and the test section remained in a drenched condition for some little time. On the open-textured test sections, however, the surface did not remain drenched, particularly when the pavement temperature was well over 100 F , as was the case for the majority of the testing program. It was impossible to maintain a continuous water film on these coarse-textured pavements, and the water quickly evaporated from the tops of the projecting aggregate. As a result, there was not complete consistency in the degree of saturation of the pavement test surfaces. This would tend to result in relatively higher skidding-resistance values for open-textured surface types than for dense surfaces, when evaluated by the field stopping-distance method.

The second possible source of difference was the presence of the film of oil drippings, worn rubber, and dust on the highway during testing. Previous research (2, 6) has noted this film as a factor contributing to the so-called seasonal effect, since it is more pronounced during the summer months. It has also been noted that a dense surface is more sensitive to the seasonal effect than an open-textured one. During the coring operation, in which the abrasive and ground-up aggregate swirled around on the surface of the core, and subsequent cleaning of the test specimen, prior to testing, this seasonal film was removed. This resulted in the laboratory test method indicating a relatively higher skidding resistance for a dense surface than for an open-textured surface, as compared to the field method.

A final factor to be considered, which would apply to the Kentucky rock asphalt specimens only, is that previous research (1) has shown

that this type of surface possesses nearly uniform high anti-skid characteristics for all speed ranges. The majority of the surface types, however, exhibit a marked decrease in resistance as speed increases (2, 4). The stopping-distance method measures a resistance value which represents an integrated average of the total resistance developed, as the vehicle is skidding from the speed at which the brakes are applied down to zero speed. The laboratory method, on the other hand, evaluates the resistance at a constant speed.

The stopping-distance method, therefore, for a surface which exhibits uniform anti-skid resistance for all speed ranges, would give an evaluation of the skidding resistance which would be the same for all speeds, and this value whould conform fairly closely to the resistance as determined by the laboratory method. For a surface type which shows higher skidding resistance at the lower speed ranges, however, the stopping-distance method, since it reflects the frictional force being developed over the entire speed range, would indicate that the surface exhibits better skidding resistance than would the laboratory method, which evaluates the specimen at high speed only.

As a result, the stopping distance method measures a relatively higher skidding resistance than the laboratory method for surfaces which exhibit a decrease in skidding resistance with speed, while the laboratory method indicates a relatively higher resistance for the Kentucky rock asphalt surfaces which possess uniform skidding resistance at all speed ranges. This is illustrated in Figure 18 by the marked deviation of the points corresponding to the three Kentucky rock asphalt surfaces from the linear correlation line.

After considering the results of this correlation study, it was decided that the laboratory skid-test apparatus would be entirely satisfactory for a laboratory investigation of factors affecting the skidding resistance of bituminous paving mixtures. Although some discrepancy exists between results obtained by the field and laboratory methods, it was felt that the factors contributing to this discrepancy tended to favor the laboratory method as giving a more realistic evaluation of the skidding resistance of a wet pavement surface for speeds of 30 mph and upward. The laboratory method would probably have shown closer agreement with the truck-trailer method of determining skidding resistance on the highway, since both of these methods evaluate the test surfaces at a constant speed. Unfortunately, equipment of this nature was not available for the correlation study.

PREPARATION OF THE STANDARD LABORATORY SPECIMEN

The primary consideration in the molding of the laboratory test specimens was to arrive at a surface condition which was representative of the texture that a similar mix would exhibit on a highway surface. Although the specimen had to possess sufficient surface durability to prevent disintegration under the severe action of the wearing procedure, stability and density, as such, were not considered important to this study, and no measurements of these properties were made.

The following procedure refers to the standard laboratory specimen on which the results reported in this paper are based. Although the aggregate gradation for a standard specimen is included in this section, a description of the aggregates themselves is presented with the results.

Materials

An 85-100 penetration grade asphalt cement furnished by the Texas Company from the Port Neches refinery was used for all of the test specimens molded in the laboratory. Standard test results are listed in Table 3.

The asphalt content selected for the standard laboratory specimen was 4.5 percent, based on the total weight of the bituminous mixture. In arriving at this selected value, mixes ranging in asphalt content from 3.5 to 6.5 percent were investigated, with the 4.5 percent figure representing the best compromise. It seemed desirable to keep the mix as lean as possible in order to prevent the asphalt from flushing to the surface during the wearing procedure and obscuring the polishing characteristics of the aggregate, while too low an asphalt content resulted in a mixture which exhibited poor surface stability during the severe wearing procedure.

The bituminous-concrete mixture chosen for the standard laboratory specimen conformed to the specifications of the State Highway Department of Indiana for Hot Asphaltic Concrete - Type B (Medium Texture), except for the asphalt content, which was kept low as explained above. Table 4 lists the specification limits, adjusted to conform to the sieve series used in this investigation, and the selected composition for the standard specimen. Figure 19 shows a plot of the aggregate grading listed in the right-hand column of Table 4.

TABLE 3

Results of Standard Tests on Asphalt Cement

Test	Results
Specific Gravity 77/77 F	1.010
Softening Point, Ring and Ball, F	118
Ductility, cm	200 +
Penetration, 100 grams, 5 sec., 77 F	93
Penetration, 100 grams, 5 sec., 32 F	28
Flash Point, Cleveland Open Cup, F	565
Loss on Heating, 50 grams, 5 hours, 325 F, percent	0.03
Penetration on Residue, 77 F, percent of original	91
Solubility in Carbon Tetrachloride, percent	99.86
Oliensis Spot Test	Negative

TABLE 4

Indiana Specification Limits for Hot Asphaltic Concrete - Type B
and
Mixture Composition Used for Standard Laboratory Specimens

Passing Sieve	Retained on Sieve	Type B Limits in Percent Minimum	Type B Limits in Percent Maximum	Selected Composition in Percent
1/2 inch	3/8 inch	2	14	12
3/8 inch	No. 4	20	50	36
No. 4	No. 8	0	22	10
No. 8	No. 16	5	20	11
No. 16	No. 30	5	13	12
No. 30	No. 50	5	12	11
No. 50	No. 100	2	17	3
No. 100	No. 200	1	5	2
No. 200	———	3	5	3
Bitumen		6.5	8.5	4.5

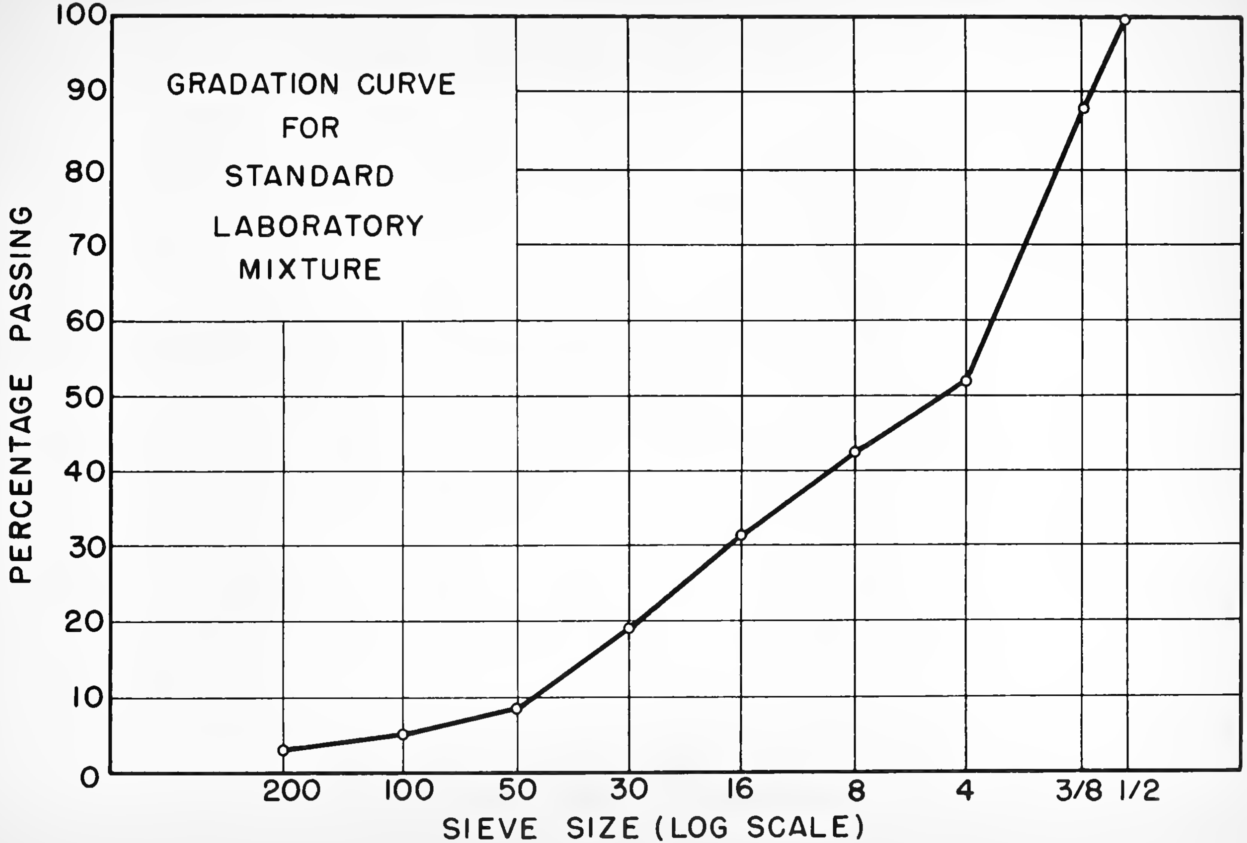

GRADATION CURVE
FOR
STANDARD
LABORATORY
MIXTURE
PERCENTAGE PASSING
100
90
80
70
60
50
40
30
20
10
0
200
100
50
30
16
8
4
3/8
1/2
SIEVE SIZE (LOG SCALE)

FIG. 19

In establishing this gradation as the standard composition, preliminary tests were performed on a wide variety of mixtures ranging in texture from a very dense mix, with the gradation conforming to Fuller's maximum density curve, to an extremely open one which was essentially a one particle size mixture. The asphaltic concrete Type B mixture appeared to give the most satisfactory surface texture and degree of coarse aggregate exposure of any of the mixtures tested.

Batching, Mixing, and Molding Procedure

Most of the mineral aggregates used in this study were received in a crushed condition with the coarse and fine aggregate fractions combined. A few ledge samples were obtained, and these were reduced to suitable sizes in a DFC No. 2 Crusher made by the Denver Fire Clay Company and an Iler Improved Grinder of the Fen Machine Company, Cleveland, Ohio. In order to achieve a high degree of control over the aggregate gradation, the mineral aggregates were first separated into the various sieve size fractions, after which they were recombined in the desired proportions.

For most of the specimens, a 2000-gram sample of aggregate resulted in a bituminous mixture which was sufficient for filling the 6-inch diameter specimen to a compacted depth of 2 inches. On some of the very harsh, angular aggregates, however, which were difficult to compact, this value had to be reduced to 1900 grams to keep from overflowing the mold. Three test specimens were made for each mixture, and three different mixtures were molded and tested at a time, giving a total of nine specimens for each series.

A complete mixing and molding procedure for a standard laboratory test specimen consisted of the following steps:

1. The batched sample of aggregate and the asphalt cement were placed in separate containers in a Peerless gas oven and brought up to a temperature of 300 ± 10 F. A short time prior to mixing, the molds, mixing bowl, paddle, etc. were also placed in the oven.

2. When the materials reached the proper temperature, the heated flat-bottomed mixing bowl was placed on a beam balance and was tared. The aggregate was then placed in the bowl and its weight determined to the nearest gram, which provided a check on the batching operation. A weight equivalent to the amount of asphalt cement to be incorporated into the mixture was added to the beam, and the hot asphalt was then poured into the bowl until the beam again balanced.

3. The mixing bowl was next placed on the Hobart electric mixer and the aggregate and asphalt mixed together for 2 minutes with the equipment operating at slow speed.

4. The mixture was then transferred with a large metal spoon to the test specimen mold, which was fitted with a collar to confine the uncompacted mix. All metal parts which came into contact with the mixture were heated prior to contact.

5. The surface of the mixture was smoothed with the metal spoon and a 1/2-thick steel circular plate, having a diameter of 1/8 of an inch smaller than the inside diameter of the mold, was then placed directly on the surface. The mixture was vibrated for one minute with a Cleveland pneumatic vibrator, as illustrated in Figure 20. On the left side of this figure is shown a specimen being vibrated with the collar, bearing plate, bearing block, and vibrator in place, and on the right, a completed specimen.

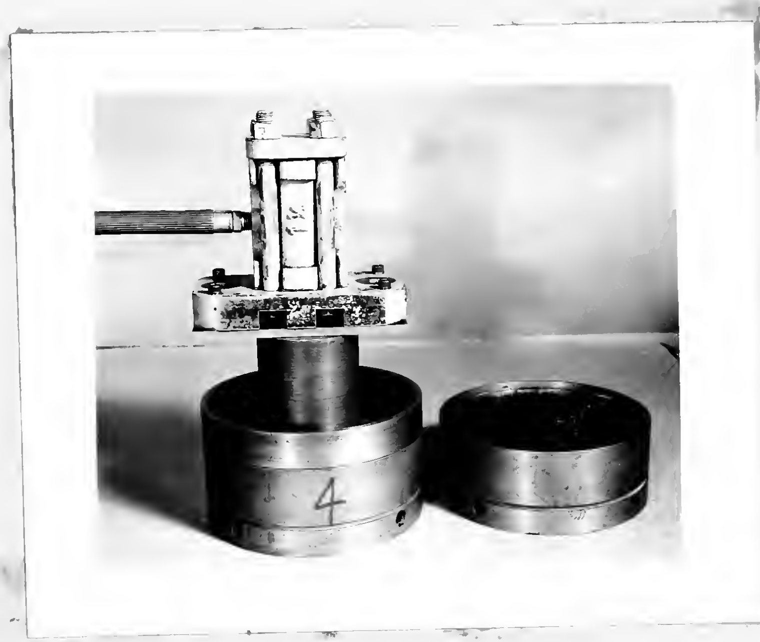
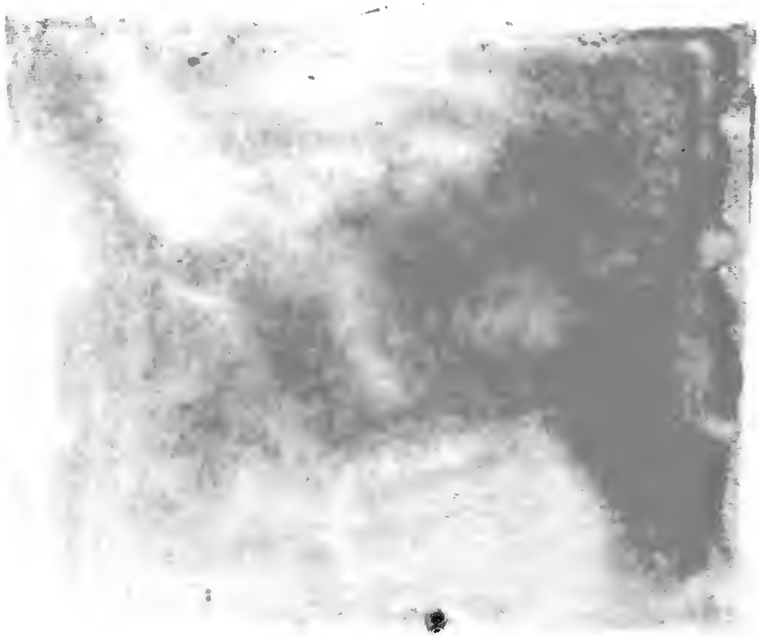


Fig. 20 Laboratory Vibration Equipment and Test Specimen Mold



6. At the completion of the vibration the specimen was permitted to cool at room temperature for 30 minutes at which time it was placed in an oven, maintained at 140 F, for an additional 30 minutes.

The specimen was then ready for the first rolling process of the wear and polishing procedure, which is described in a previous section.

RESULTS OBTAINED IN THE LABORATORY INVESTIGATION

In order to illustrate the variation in skidding resistance that a test specimen experiences during an entire wear and polishing procedure, the three curves of Figure 21 are presented. The top curve is for a test specimen made with Kansas quartzite which exhibited the best resistance to polishing of any of the mineral aggregates investigated to date. The middle curve is for a specimen containing Massachusetts rhyolite which, if subjected to a wearing effort appreciably greater than that corresponding to the standard wearing procedure, can be made to polish. The lower curve represents an Indiana oolitic limestone specimen which possesses very little resistance to polishing.

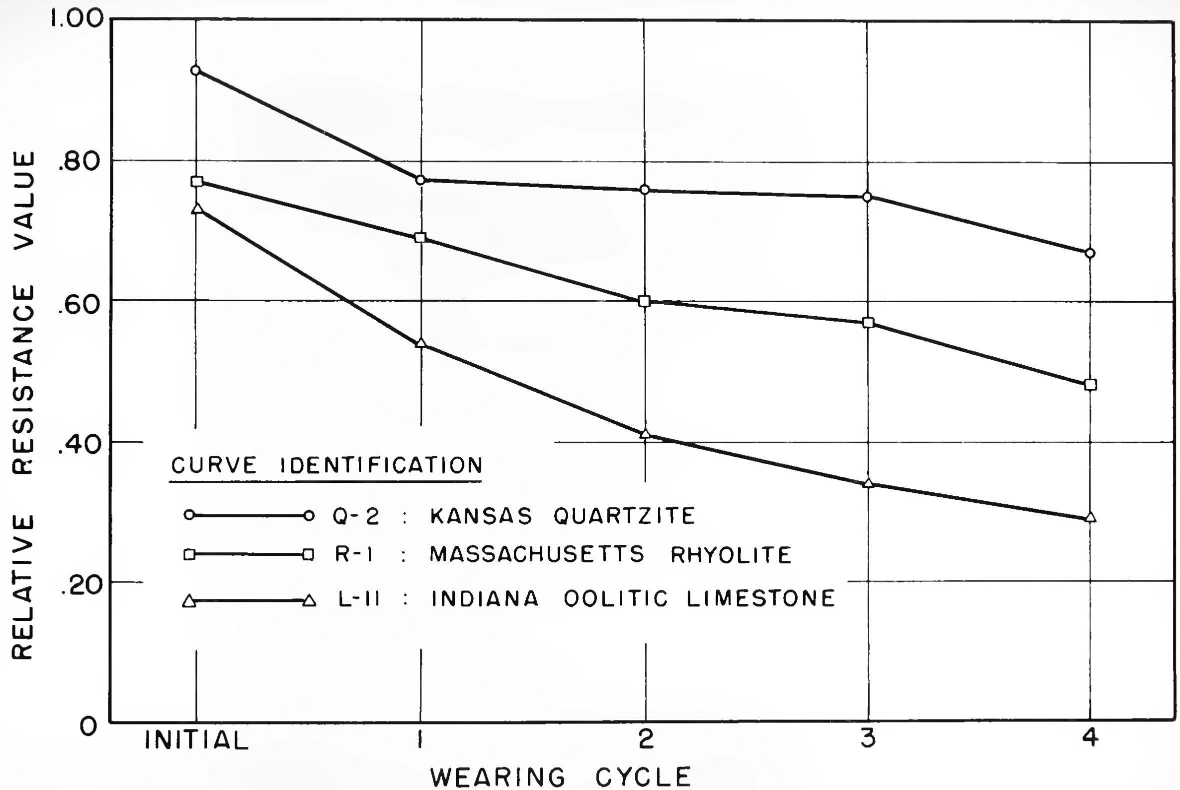


FIG.21 VARIATION IN SKID RESISTANCE OF BITUMINOUS MIXTURES WITH WEAR

It should be noted, in all fairness, that some of the Indiana limestones which have been tested have shown as high a resistance to polishing as the Massachusetts rhyolite. The limestone, on which the data plotted in Figure 21 was obtained, is the poorest from the polishing standpoint of any of the Indiana limestones tested thus far. A limestone supplied by another state for this investigation has exhibited even poorer polishing characteristics, however, so the problem of aggregate polishing is not unique with Indiana.

The five points plotted for each of the curves in Figure 21 correspond to a specific position in the wearing and polishing procedure. The initial relative resistant values were determined after the specimens had been vibrated for 1 minute and allowed to cool. The next series was obtained after the specimens had been rolled for 2 minutes with the conical rollers. The points listed for wearing cycle No. 2 were taken after the specimens were subjected to coarse wear in the skid-test apparatus. The next results correspond to values obtained at the conclusion of the fine-polishing portion of the procedure, and the final points represent the values obtained at the completion of the light rolling operation, which coated the aggregate with a very thin film of asphalt.

In comparing the relative resistance to polishing of the various aggregates, the results obtained at the completion of the fine-polishing procedure are probably the most significant. This corresponds to wearing cycle No. 3 in Figure 21. At this point in the wearing procedure the test specimen has a clean, polished surface with a texture quite similar to that of a well-worn highway surface. Subsequent rolling will coat the aggregate and decrease the skidding resistance

of the test specimen, but it is debatable as to how realistically this procedure duplicates the traffic film existing on the pavement surface during certain seasons of the year. At the completion of the final polishing, the relative resistance values for specimens made from quartzite, rhyolite, and limestone were 0.75, 0.57, and 0.34, respectively.

CONCLUSION

The laboratory skid-test apparatus has operated satisfactorily for one year, while the wear and polishing procedure, as finally evolved, has been in use for about six months. It appears that this equipment and procedure will prove adequate for a laboratory investigation of factors affecting the skidding resistance of pavement surfaces. Current and future research studies with this equipment include an evaluation of the effect of the type of aggregate, the particle shape, and the surface texture on the skidding resistance of bituminous surfaces. Investigations will be made for improving the skidding characteristics of bituminous mixtures containing aggregates that polish readily by blending a more resistant material with the polish-susceptible aggregate. Related research will also take place with portland cement concrete.

Some endeavor will be made to correlate the wearing procedure with actual traffic wear. Although the polishing effort corresponding to the wearing procedure is sufficient to reduce a bituminous surface containing a polish-susceptible aggregate to its most slippery condition, it may prove to be inadequate for duplicating the polishing effect of anticipated traffic on some of our major highways.

ACKNOWLEDGMENTS

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